Justice, Exclusion, and Equity: An Analysis of 48 U.S. Metropolitan Areas

Chelsey Palmateer
Ph.D. Candidate
University of Minnesota
Department of Civil, Environmental, and Geo- Engineering
500 Pillsbury Drive SE, Minneapolis, MN 55455 USA
palma040@umn.edu

David Levinson
Professor
University of Sydney
School of Civil Engineering
david.levinson@sydney.edu.au

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ABSTRACT

Injustice in transportation services experienced by disadvantaged demographic groups account for much of these groups' social exclusion. Unfortunately, there is little agreement in the field about what theoretical foundation should be the basis of measures of the justice of transportation services, limiting the ability of transportation professionals to remedy the issues. Accordingly, there is a need for an improved measure of the justice of the distribution of transportation services, which relates to the effectiveness of transportation services for all members of disadvantaged groups rather than for only segregated members of these disadvantaged groups. To this end potential measures of distributive justice, based on the accessibility to jobs provided by various modes, are evaluated in 48 of the top 50 largest metropolitan areas in the United States. The purpose of the study is to inform recommendations for appropriate use of each measure.

Keywords: Distributive Justice; Equity; Accessibility; Transportation

INTRODUCTION

Studies have shown that injustice in transportation services experienced by disadvantaged demographic groups account for much of these groups' social exclusion.[9] [11] [4] However, there is little agreement in the field about what theoretical foundation should be the basis of measures of the justice of transportation services, limiting the ability of transportation professionals to remedy the issues. Furthermore outside of academia, many attempts to quantify justice in transportation projects and systems rely on proximity to concentrations of disadvantaged demographic groups. As a result decisions based on this type of quantification exclude consideration of members of disadvantaged groups who do not live in close proximity to one another and additionally fail to indicate the effectiveness of the provided transportation services.

Accordingly, there is a need for an improved measure of the justice of the distribution of transportation services, which relates to the effectiveness of transportation services for all members of disadvantaged groups rather than for only segregated members of these disadvantaged groups. Furthermore an effort to better understand the implications of each of the potential theoretical foundations of the justice measure is necessary. To this end potential measures of distributive justice, based on the accessibility to jobs provided by various modes, are evaluated in 48 of the top 50 largest metropolitan areas in the United States.

In this context accessibility is the ability of system users to reach desirable destinations, such as jobs, via a given mode. Accessibility is a direct measure of transportation services and can account for individuals in areas with concentrations of their demographic groups as well as those living outside of such areas of concentration. These potential measures of distributive justice are regressed on combinations of the population of the metropolitan area, the density of those populations, the land area of the metropolitan area, and indices of segregation for disadvantaged populations.

The goal is to inform recommendations for appropriate use of each measure, based on existing transportation policies regarding justice in the provision of transportation services.

THEORY

Accessibility: A Concept of the Service Provided By Transport Facilities

Accessibility is the ability with which users of a given mode may reach desirable destinations. It is important to distinguish accessibility from mobility, which is concerned with the speed provided to travelers, rather than their ability to reach destinations. Modern measures of accessibility can be traced back to a 1959 article by Hansen regarding the relationship between accessibility and land use. [8] In that article Hansen describes accessibility as a summation of weighted potential destinations. [6]

$$a_i = \sum_j o_j f(C_{ij}) \tag{1}$$

Where:

a_i = accessibility for location i

o_j = number of opportunities at location j

C_{ij} = cost of travel from i to j

$f(C_{ij})$ = weighting function

Cumulative opportunity accessibility calculations are one form of gravity weighting summation in which one of the simplest weighting functions, a binary weighting function, is employed. Basically, opportunities that can be reached within a given threshold are weighted with a value of one, and those that cannot be reached are weighted with a value of zero as in Equation 2. [8]

$$f(C_{ij}) = \begin{cases} 1 & \text{if } \mathrm{C}_{ij} \leq t \\ 0 & \text{if } \mathrm{C}_{ij} > t \end{cases} \tag{2}$$

Where:
t = travel time threshold

A set of destinations reachable within each travel cost threshold is identified for each origin and the jobs located at the reachable destinations are aggregated to arrive at a single accessibility data point for that origin. This measure can be further aggregated to a regional level as the person-weighted accessibility within threshold (t) experienced by individual members of a representative group (S), see Equation 3.

$$A_t = (\sum_i a_{it} S_i)/(\sum_i S_i) \tag{3}$$

Distributive Justice: A Brief Review of Four Theoretical Concepts

There are many theoretical foundations of justice, as a result any discussion of justice must involve multiple competing concepts. The analysis that follows is limited to four concepts of distributive justice commonly found in the literature: absolute or minimum need, equality of opportunity, the Maxi-Min Theory of Justice, and relative need. A brief overview of each of these is included below. These concepts can be organized in a variety of ways, but in this paper the focus starts with the simplest concept and increases in complexity based on the number of variables under consideration.

Absolute Need

The simplest concept of distributive justice is that of absolute or minimum need. This version of distributive justice focuses on the provision of a basic minimum allocation to all individuals. The concept is founded in the idea that there are minimal resources to which everyone is entitled. For example, individuals are entitled to the resources needed to survive, such as access to fresh water and the means to clean it. [3] [7] However, it is difficult to define a set minimum allocation of resources, because society tends to define the minimum acceptable level of allocation relative to the general abundance of resources. Greenburg [5] discusses the tendency for abundance to shift the focus from providing a minimum based on the requirements of survival to providing a minimum based on the requirements of enjoying a meaningful life within a society.

As it relates to transportation services and the provision of access to jobs, a basic minimum allocation could be seen as a set number of jobs within a certain time frame. Unfortunately, an obvious and logical choice in the number of jobs that individuals should be able to reach in a given time frame is not readily available. Consider the case of a farmer, living in a rural area. Arguably, the farmer has a job which may very well be the only job opportunity for miles. Yet, the farmer is able to support his needs. As an alternate example consider a person living in a large city. This potential worker likely could reach thousands of jobs in a reasonable time frame, but his neighbors and many others could also reach the same jobs. As such the individual must compete for nearby jobs. Although numerous studies have shown that individuals budget their travel time, and that average commute times have remained similar through time, it is commonly recognized that some individuals are willing to spend more time commuting for a variety of reasons. Furthermore, recent decades have seen the popularization of telecommuting, allowing individuals to opt to work from home. As such any definition of a minimum allocation of job access is arbitrary. The definition can still be useful.

Furthermore, a more in depth analysis would also take into account competition for jobs. This paper considers a potential measure which accounts for competition: a ratio of the individual's access to jobs over the individual's access to other potential workers, within a time-frame that would fit in a standard time budget for travel to work.[13] The equations for the ratio, described as the opportunity level at a threshold and location, is shown in Table 1, under the heading *Minimum Allocation: Absolute Need*. Note, this equation is based on the assumption that every individual at a location has the same access to jobs and competing workers.

Equality of Opportunity

Equality of opportunity is a slightly more complex concept of distributive justice. This concept has been largely developed by Peter Westen, and is founded on the idea that opportunity is a relationship between three factors: an individual, a goal, and any obstacles between the individual and the goal. Note that if there are any obstacles which the individual cannot surmount, than there is not an opportunity to achieve the goal. Some of these obstacles may not be related to the goal, but rather based on hierarchical or caste-based discriminatory practices. These obstacles are hereafter referred to as unrelated obstacles. In order to achieve equality of opportunity individuals wishing to achieve the same goals would face similar obstacles, and none of those obstacles would be unrelated or insurmountable.[12]

As it relates to transportation services and the provision of access to jobs, representative groups of individuals based on such factors as income, race, ethnicity, age, religion, and gender should have the same opportunity to obtain work based on their skills. By this logic, the opportunity level of an individual defined for minimum allocation above can be averaged within representative groups to determine if equality of opportunity exists between members of different groups. Distributive justice would be achieved if the opportunity level at a threshold was equal between groups, or if there were no statistically significant difference between the opportunity levels for the various groups. The equation for the person-weighted opportunity level of a representative group is shown in Table 1, under the heading *Equality of Opportunity*.

The Maxi-Min Theory of Justice

The Maxi-Min Theory of Justice, developed by John Rawls, allows for the possibility of justice in a distribution without direct equality. Rawls proposes two principles of justice, with the requirement that the first principle be completely satisfied before the second principle is considered:

1. "each person is to have an equal right to the most extensive scheme of equal basic liberties compatible with a similar scheme of liberties for others". [10]
2. "social and economic inequalities are to be arranged so that they are both (a) to the greatest expected benefit of the least advantaged and (b) attached to offices and positions open to all under conditions of fair equality of opportunity". [10]

Applied to transportation we interpret Rawls to mean that the higher the level of benefit, in this case access to jobs, provided to the group with the least benefit, the more equitable a transportation system is.

Equations for determining the level of access for representative groups at a threshold and overall are shown in Table 1 under the heading *Maxi-Min Theory of Justice*.

Relative Need

Finally, the most complex form of distributive justice explored in this paper focuses on distributing resources based on the relative need of the recipients. In many studies of the distributive justice of transport networks, such as that performed by Benenson et al [1], the evaluation of the gap between transit and automobile accessibility is explored. The concern is for individuals without access to an automobile and how their accessibility compares to those who do have access to an automobile.

One way to calculate this is to find the net access within a threshold available via automobile, to see how much of an advantage users obtain if they can afford a car, over those who cannot. Similarly, it is also possible to find the net access available within a threshold via transit, to see how much of an advantage users obtain if they can afford transit, over those who cannot. However, this is a simplification. Alternatively, the gap could be calculated as the difference between the access levels of the automobile owners representative group and the transit owners representative group. However, a greater gap may result from more jobs rather than poor transit service. To that end a ratio of the access available to the two representative groups is proposed. Equations for each of these measures can be found in Table 1 under the heading Relative Need.

An alternative relative need based distributive justice concept involves the combination of the tax based concepts of horizontal equity and vertical equity. [7] Horizontal equity states that individuals of equal standing should be taxed equally, and receive equal benefits associated with those taxes. Vertical equity states that disadvantaged groups should pay lower taxes than advantaged groups and furthermore that benefits associated with taxes should be distributed in such a way as to provide greater benefit to disadvantaged groups.

The concepts of horizontal and vertical equity are frequently used to evaluate transport systems. Delbosc and Currie [2], use the concepts of horizontal and vertical equity in their 2011 assessment of public transport distributive justice. They evaluate the distributive justice of the public transport system in Melbourne using Lorenz curves and the Gini coefficient. As applied in this paper, the Gini coefficient is negative if lower income groups have relatively high levels of access to jobs in comparison to higher income groups, positive if the higher income groups have relatively higher levels of access, and zero if the groups have the same levels of access. The equation for the caculation of the Gini coefficient is shown in Table 1 under the heading Need-Based.

TABLE 1 : Operationalized Distributive Justice Concepts

Minimum Allocation: Absolute Need		
Difference in Access to Jobs and Access to Workers at Location (i) within Threshold (t)	$a_{jobs,it} - a_{workers,it}$	(4)
Opportunity Level at Location (i) within Threshold (t)	$o_{it} = \frac{a_{jobs,it}}{a_{workers,it}}$	(5)
Equality of Opportunity		
Compare Person-Weighted Opportunity Level within Threshold t Experienced by various Representative Groups	$O_t = (\sum_i o_{it} S_i)/(\sum_i S_i)$	(6)
Maxi-Min Theory of Justice		
Minimum Person-Weighted Accessibility within Threshold (t) Experienced by a Representative Group	$Min \quad A_t = (\sum_i a_{it} S_i)/(\sum_i S_i)$	(7)
Minimum Person-Weighted and Time-Weighted Accessibility Experienced by a Representative Group	$Min \quad A = \sum_i (A_t - A_{(t-y)}) e^{\theta t}$	(8)
Relative Need		
Gini Coefficient	$G \approx 1 - \sum_{k=1}^{K} (p_k - p_{k-1})(a_k + a_{k-1})$	(9)
Net Auto Person-Weighted Accessibility within Threshold t	$A_{netauto,t} = A_{auto,t} - A_{transit,t}$	(10)
Net Transit Person-Weighted Accessibility within Threshold t	$A_{nettransit,t} = A_{transit,t} - A_{walk,t}$	(11)

Continuation of Table 1	
Gap in Person-Weighted Accessibility within Threshold t between People who Have an Automobile and People who Don't Have an Automobile	$$A_{hasauto,t} = (\sum_i a_{auto,it} S_{hasauto,i})/(\sum_i S_{hasauto,i})$$ $$A_{noauto,t} = (\sum_i a_{transit,it} S_{noauto,i})/(\sum_i S_{noauto,i})$$ $$A_{needgap,t} = A_{hasauto,t} - A_{noauto,t} \quad (12)$$
Ratio of Transit Person-Weighted Accessibility within Threshold t to Auto Person-Weighted Accessibility within Threshold t	$$A_{netauto,t} = \frac{A_{transit,t}}{A_{auto,t}} \quad (13)$$
Ratio of Person-Weighted Accessibility within Threshold t of People who Don't Have an Automobile to Person-Weighted Accessibility within Threshold t of People who Have an Automobile	$$Z_{needratio,t} = A_{noauto,t}/A_{hasauto,t} \quad (14)$$
End of Table	

A DESCRIPTION OF THE 48 U.S. METROPOLITAN AREAS

The 48 United States Metropolitan Areas evaluated in this study are the top largest 50 Core Based Statistical Areas (CBSA) by population, excluding Memphis and Kansas City due to issues with data collection. Figure 1 provides information regarding the population, land area, population densities, and mean travel time to work for each of the metropolitan areas and is arranged from largest population to smallest. Figure 1 has a color gradient, with the darkest green representing the highest values in each category and white representing the lowest values.

As can be seen the New York City Metropolitan Area has the largest population, overall and weighted population densities, and mean travel time to work. In fact, the population and weighted population density in the New York City Metropolitan Area far exceed the next largest metropolitan area in either category. As a result it is anticipated that the New York City Metropolitan Area may generally be an outlier. The Riverside Metropolitan Area has the largest land area by far and may also be an outlier. In contrast, the Salt Lake City Metropolitan Area has the smallest population and overall population density. The Milwaukee Metropolitan Area has the smallest land area. The Birmingham Metropolitan Area has the smallest weighted population density. Finally, the Buffalo Metropolitan Area has the lowest mean travel time to work. In general, these lowest values do not appear to be outliers.

Another characteristic is the number of jobs and workers, stratefied by income in each metropolitan area. Note, that the breakdown of workers/jobs into the three categories of high, middle, and low income is not even. As defined by the U.S. Census Bureau the low income bracket applies to incomes less than or equal to $1,250/month, the middle income bracket applies to incomes from $1,251/month to $3,333/month, and the high income bracket applies to incomes greater than $3,333/month. These definitions were originally developed to divide workers/jobs into three even groups, but several years have passed since that time and inflation has caused the relative percentage of workers/jobs in each group to shift.

The actual portions in each metropolitan area vary, but the high income brackets for workers and jobs generally include approximately 50% of the workers and jobs respectively, the middle income brackets for workers and jobs generally include slightly more than 25% of the workers and jobs respectively, and the low income brackets for workers and jobs generally include slightly less than 25% of the workers and jobs respectively. As a result, direct comparison between these categories is inadvisable due to inevitable bias towards more jobs and workers as income levels increase. For this reason, the majority of the analysis will focus on access to all jobs, by a typical member of various representative worker groups.

ACCESS TO JOBS IN 48 U.S. METROPOLITAN AREAS

Prior to this analysis access to jobs and workers, broken down by income, was calculated for every census block in each of the 48 metropolitan areas, via four modes: automobile, transit, bicycle, and walking. This data was provided for use in this study by the Accessibility Observatory at the University of Minnesota. Data was available for six time thresholds: 10, 20, 30, 40, 50, and 60 minutes. However, see Figure 1, only the threshold closest to the average mean travel time to work for all 48 metropolitan areas, which is the 30 minute threshold, is used in this analysis.

DISTRIBUTIVE JUSTICE MEASURES IN 48 U.S. METROPOLITAN AREAS

Minimum Allocation: Absolute Need

As noted in the theory section, it can be difficult to determine what minimal resources individuals are entitled too, especially in areas where general abundance inflates the social understanding of what a meaningful life within society entails. Transportation is one of those areas. So rather than selecting a single minimum basic requirement for transportation and evaluating if anyone falls below it, ratio of access to jobs over access to workers is spatially evaluated.

As can be seen in Figure 2, maps of opportunity level at a location and threshold allow for easy visualization of the opportunity to competition ratio, where opportunity is access to jobs and competition is access to workers, available to workers throughout a region. The ability to visualize these disparities is valuable in locating problem areas, such as the aforementioned bedroom communities, within a region. This technique can be especially valuable in determining where there may be issues with spatial mismatch of jobs and workers by industry, education level, or income level by simply looking at subsets of job opportunities and competing workers based on the specific type of job and worker of interest. This is particularly useful in scenario comparisons for projects and before and after type analysis. However the measure discussed is unable to provide aggregate information on the community as a whole, and is therefore a poor choice for comparing between regions.

Metro Area	Population (2010)	Land Area	Overall Population Density	Weigted Population Density	Mean Travel Time to Work (minutes)
New York	18,897,109	6,686.90	2,825.99	31,251.44	36.30
Los Angeles	12,828,837	4,848.45	2,645.97	12,113.88	30.00
Chicago	9,461,105	7,196.81	1,314.63	8,613.39	31.80
Dallas	6,371,773	8,927.50	713.72	3,909.28	28.10
Philadelphia	5,965,343	4,602.10	1,296.22	7,773.15	29.60
Houston	5,946,800	8,827.49	673.67	4,109.60	30.20
Washington DC	5,582,170	5,598.32	997.12	6,388.08	34.40
Miami	5,564,635	5,077.26	1,095.99	7,395.31	29.10
Atlanta	5,268,860	8,338.54	631.87	2,172.95	31.30
Boston	4,552,402	3,487.41	1,305.38	7,980.11	31.40
San Francisco	4,335,391	2,470.54	1,754.83	12,144.94	33.20
Detroit	4,296,250	3,888.40	1,104.89	3,800.37	26.60
Riverside	4,224,851	27,263.42	154.96	4,299.61	31.90
Phoenix	4,192,887	14,565.75	287.86	4,394.95	26.20
Seattle	3,439,809	5,872.35	585.76	4,721.61	30.20
Minneapolis	3,279,833	6,027.17	544.17	3,383.39	25.40
San Diego	3,095,313	4,206.63	735.82	6,920.54	26.10
St. Louis	2,812,896	8,623.24	326.20	2,742.46	25.60
Tampa	2,783,243	2,513.44	1,107.35	3,323.02	27.00
Baltimore	2,710,489	2,601.48	1,041.90	5,435.72	30.60
Denver	2,543,482	8,346.06	304.75	4,803.69	27.70
Pittsburgh	2,356,285	5,281.48	446.14	2,990.76	26.60
Portland	2,226,009	6,683.75	333.05	4,372.60	26.60
Sacramento	2,149,127	5,094.22	421.88	4,538.49	26.90
San Antonio	2,142,508	7,312.64	292.99	3,475.43	26.40
Orlando	2,134,411	3,478.48	613.60	2,774.65	27.90
Cincinnati	2,130,151	4,391.88	485.02	2,563.64	24.90
Cleveland	2,077,240	1,997.31	1,040.02	3,808.39	24.70
Las Vegas	1,951,269	7,891.43	247.26	6,527.24	25.00
San Jose	1,836,911	2,678.81	685.72	8,417.75	28.10
Columbus	1,836,536	3,967.20	462.93	3,185.97	23.60
Charlotte	1,758,038	3,085.19	569.83	1,881.26	26.90
Indianapolis	1,756,241	3,854.46	455.64	2,285.64	24.90
Austin	1,716,289	4,219.89	406.71	3,131.45	26.50
Virginia Beach	1,671,683	2,629.59	635.72	4,084.07	24.80
Providence	1,600,852	1,586.91	1,008.79	4,763.75	26.20
Nashville	1,589,934	5,688.65	279.49	1,695.26	27.40
Milwaukee	1,555,908	1,454.76	1,069.53	5,257.59	23.10
Jacksonville	1,345,596	3,201.08	420.36	2,158.71	26.20
Louisville	1,283,566	4,110.86	312.24	2,477.34	24.10
Richmond	1,258,251	5,684.96	221.33	2,175.69	24.50
Oklahoma City	1,252,987	5,511.56	227.34	2,568.79	22.50
Hartford	1,212,381	1,514.61	800.46	3,250.88	23.90
New Orleans	1,167,764	2,960.19	394.49	4,370.22	25.90
Buffalo	1,135,509	1,565.05	725.54	4,129.44	22.00
Raleigh	1,130,490	2,118.20	533.70	1,850.15	25.90
Birmingham	1,128,047	5,279.51	213.66	1,314.15	26.20
Salt Lake City	1,124,197	9,555.35	117.65	4,563.51	22.30
Average	**3,389,201**	**5,474.32**	**726.46**	**5,047.72**	**27.22**

FIGURE 1 : Characteristics of the Metropolitan Areas Evaluated in this Study

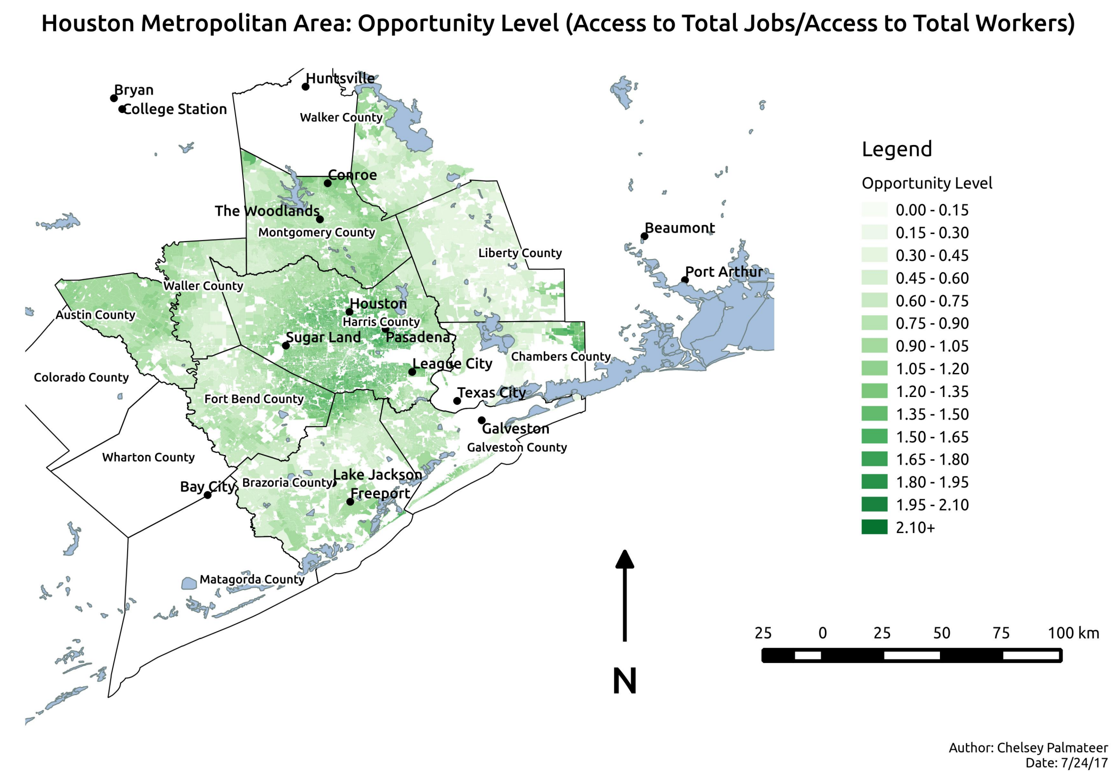

FIGURE 2 : Houston Metropolitan Area: Opportunity Level provided within 30 Minutes

Equality of Opportunity

As noted in the theory section, equality of opportunity requires that individuals all have an opportunity to reach a goal or desired outcome, such as accessing a job, without needing to overcome unrelated obstacles. In this study the goal is access to sufficient jobs to obtain a single job, and one potential unrelated obstacle might be high travel times reducing access for low income workers. In order to evaluate this, a person-weighted measure, which builds on the measure discussed in the previous section is utilized, see Equation 6. Basically, the goal is to compare the opportunity level, or person-weighted ratio of access to jobs over access to workers within 30 minutes, as experienced by each income group. However, there are several ways to approach this task.

To help clarify the potential opportunity level definitions, consider Table 2. This table has three rows of data, one row for each of the income brackets that the opportunity levels were person-weighted by. In addition, there are four columns of data. The first column relays the person-weighted ratio of access to low income jobs over access to low income workers. The second column does the same but for middle income jobs and workers rather than low income. The third column relays the person-weighted ratio of access to high income jobs over access to high income workers. The final column, relays the person-weighted ratio of access to all jobs over access to all workers. Ideally, an analysis regarding a person's opportunity to find a job would focus on jobs within that person's income bracket, or presumed skill level. However, due to the uneven distribution of the income brackets noted previously this leads to some bias. In particular note that in general, regardless of the income bracket that the opportunity level has been person-weighted over, the person-weighted high income opportunity level is greater than the person-weighted middle income opportunity level, which is greater than the person-weighted low income opportunity level.

To avoid this bias, rather than comparing opportunity levels stratified by income for different income groups, all comparisons will be made between person weighting of differing income levels on the all incomes opportunity level.

TABLE 2 : Person-Weighted Opportunity Level (By Income) via Auto for Workers (By Income Level) for the Houston Metropolitan Area

	Opportunity Level			
Workers	**Low Income**	**Middle Income**	**High Income**	**All Incomes**
Low Income	1.0707	1.0719	1.1115	1.1048
Middle Income	1.0698	1.0703	1.1075	1.1150
High Income	1.0784	1.0744	1.1158	1.0748

Figure 3 relays the person-weighted ratio of access to all jobs over access to all workers for each income group in each metropolitan area via two modes: auto and transit. In each column, the lowest person-weighted opportunity level is indicated in white, and the cells a progressively shaded darker green with the darkest green cell having the highest person-weighted opportunity level. At first glance, regardless of the person-weighting income level, the measures seem to be around 1, but this isn't quite the case. In order to determine if the person-weighted opportunity levels for the various income levels and modes can be considered statistically equal, several homoscedastic

Student's T tests are performed. These tests check the null hypothesis that the distributions of person-weighted opportunity levels for the various income levels in the 48 metropolitan areas is essentially the same. They also assume that all of the samples have the same underlying variance, based on the analysis this assumption is believable, with estimated variances ranging from 0.0060 to 0.0085. There is one exception, the high income person weighting for transit actually has an estimated variance of 0.0217.

Interestingly the tests indicate that high income workers have statistically different opportunity levels via transit than workers with other income levels via transit, but that the high income workers have statistically similar opportunity levels between the two modes. Tests also indicate that middle income workers have statistically different opportunity levels between the two modes. However for opportunity levels via auto, there does not appear to be a statistical difference between the opportunity levels experienced by the various income groups. Together these findings show that automobiles provide equality of opportunity between income groups, assuming that everyone has access to an automobile, whereas transit does not provide equality of opportunity between income groups.

Maxi-Min Theory of Justice

Although the Maxi-Min Theory of Justice relies on equality of opportunity in regards to obtaining positions of responsibility within a society, the theory does not require an equal opportunity in regards to the distribution of benefits to all representative groups. Instead this theory is derived under the assumption that justice is achieved when working within a society raises the expected benefits of every member of that society, and maximizes the benefit experienced by the representative group of individuals who experience the least benefit. To that end Equation 7 is used to determine the person weighted access to jobs for each income level group of workers in each metropolitan area. Then the person-weighted access of the group with the least access is selected as the observed lowest access for a representative group in each metropolitan area. The results can be seen in Figure 4.

A naive analysis might apply the Maxi-Min procedure indicated in the Maxi-Min Theory at this point and declare that Los Angeles has the most just distribution of access via auto, and New York has the most just distribution of access to jobs via transit within 30 minutes as well as the most just distribution of transportation services within 30 minutes. However **??** shows that there is a clear and statistically significant correlation between the Maxi-Min access variables via transit and weighted population density. **??** also shows a similar relationship between the Maxi-Min access variable via auto and population. So when determining the justice of each of these regions by the Maxi-Min definition it is best to control for factors outside the characteristics of the transportation network, using a regression model.

Figure 5 is a graphical representation of such a comparison. Each point in the graph represents a metropolitan area and is labeled by an airport code in use within that metropolitan area. In addition there is a dashed line on the 45 degree diagonal of the chart. Points on this line indicate that the actual observed measure equals the prediction, points above the line indicate that the actual observed measure exceeds the prediction and points below the line indicate that the actual observed measure is less than the prediction. Since the Maxi-Min Theory indicates that situations are more just when the group with the least benefit is higher, metropolitan areas in which the point

Description	Low Income Auto Opportunity Level	Middle Income Auto Opportunity Level	High Income Auto Opportunity Level	Low Income Transit Opportunity Level	Middle Income Transit Opportunity Level	High Income Transit Opportunity Level
New York	1.0347	1.0396	1.0231	1.1339	1.0601	1.3940
Los Angeles	1.0279	1.0248	1.0367	1.1632	1.0979	1.2530
Chicago	1.0509	1.0605	1.0629	1.0207	1.0039	1.2156
Dallas	1.1481	1.1448	1.1602	1.0323	1.0163	1.1028
Philadelphia	1.0492	1.0466	1.0579	1.0813	1.0653	1.1378
Houston	1.1048	1.1150	1.0748	1.0949	1.0966	1.2546
Washington DC	1.1046	1.1091	1.1269	1.2211	1.1868	1.4998
Miami	1.0198	1.0197	1.0209	1.0553	1.0293	1.1695
Atlanta	1.1686	1.1607	1.2031	1.2309	1.1978	1.4748
Boston	1.1345	1.1370	1.1474	1.1838	1.1638	1.2975
San Francisco	1.1188	1.1211	1.1193	1.2103	1.1814	1.3302
Detroit	1.1059	1.1036	1.1124	1.0215	1.0008	1.0982
Riverside	0.8394	0.8481	0.8547	0.7238	0.7306	0.7444
Phoenix	1.1237	1.1244	1.1277	1.0132	0.9922	1.0181
Seattle	1.1336	1.1273	1.1687	1.1460	1.1552	1.2618
Minneapolis	1.1118	1.1122	1.1225	1.0336	1.0338	1.0330
San Diego	0.9843	0.9843	0.9960	0.9641	0.9434	1.1513
St. Louis	1.1565	1.1484	1.1677	1.1280	1.0674	1.2764
Tampa	1.1378	1.1414	1.1479	1.0283	1.0268	1.0766
Baltimore	1.0524	1.0559	1.0519	1.1443	1.1309	1.1772
Denver	1.0978	1.0956	1.1022	1.0522	1.0485	1.0806
Pittsburgh	1.1341	1.1280	1.1552	1.2047	1.1795	1.2365
Portland	1.1249	1.1287	1.1362	1.0694	1.0653	1.1103
Sacramento	1.0551	1.0522	1.0583	1.0009	0.9865	1.0187
San Antonio	1.0233	1.0208	1.0359	1.0409	1.0274	1.0259
Orlando	1.1549	1.1565	1.1513	1.0757	1.0575	1.1313
Cincinnati	1.1891	1.1843	1.1973	1.0378	1.0078	1.0051
Cleveland	1.1240	1.1234	1.1232	1.1066	1.0469	1.0897
Las Vegas	1.0084	1.0068	1.0172	0.8591	0.8680	0.7378
San Jose	1.0299	1.0291	1.0421	1.0250	1.0040	1.2091
Columbus	1.1606	1.1563	1.1771	1.0882	1.0741	1.1634
Charlotte	1.2278	1.2199	1.2484	1.1694	1.1710	1.2450
Indianapolis	1.2268	1.2244	1.2413	1.1580	1.1482	1.0969
Austin	1.1337	1.1305	1.1590	1.1419	1.1146	1.1601
Virginia Beach	1.0290	1.0271	1.0289	1.0617	1.0457	1.0327
Providence	1.0549	1.0535	1.0591	1.0589	1.0506	1.0223
Nashville	1.2273	1.2129	1.2587	1.2263	1.1363	1.2863
Milwaukee	1.1086	1.1068	1.1082	1.0727	1.0474	1.1323
Jacksonville	1.1308	1.1255	1.1470	1.0794	1.0672	1.1445
Louisville	1.1546	1.1502	1.1696	1.0418	0.9911	0.9983
Richmond	1.1624	1.1567	1.1765	1.0873	1.0578	1.0837
Oklahoma City	1.1458	1.1437	1.1594	1.0309	1.0203	0.9601
Hartford	1.1236	1.1214	1.1243	1.1396	1.1341	1.1280
New Orleans	1.0844	1.0858	1.0875	1.0450	1.0261	1.0486
Buffalo	1.0786	1.0774	1.0798	1.0368	1.0186	1.0251
Raleigh	1.3225	1.3114	1.3629	1.1524	1.1368	1.1122
Birmingham	1.2856	1.2728	1.3233	1.2045	1.1460	1.2673
Salt Lake City	1.1310	1.1243	1.1317	1.0704	1.0624	1.0243

FIGURE 3 : Person-Weighted Opportunity Level provided within 30 Minutes

is at or above the line are considered just, while those below are considered unjust.

The limitation of this particular measure is that it is unable to take into account a potential desire to mitigate issues with distributions of other benefits in society. So for example, it may be desirable, to supplement the transportation services provided to low income individuals. Rawls' system is of limited use in evaluating the potential use of transportation distribution favoring certain representative groups to mitigate other obstacles faced by those groups. To understand this, consider Figure 4 again, there are columns in the chart indicating which representative group is the group with the least benefit. Often, for both transit and auto, the representative group experiencing the lowest level of access within 30 minutes for a given region is either the high or middle income group of workers. This makes it difficult to determine what benefit the low income group receives and what difficulties they might be experiencing.

Distribution Based on Relative Need

When questions of distributing benefits to mitigate for other factors are considered, the focus is on measures which can accommodate an understanding of the relative need, due to circumstances external to the distribution of goods and services being considered, of representative groups. As noted in the discussion, the concepts of horizontal equity and vertical equity provide the focus on and understanding of how some goods, such as transportation services, are distributed similarly between some groups, such as groups defined by race, but differently between other groups, such as groups defined by income or purchasing ability. The focus here is on the distribution of transportation services as it relates to income disparities and the ability to own and maintain an automobile.

There are many potential ways to measure the relative amount of services provided to income groups and as well as the relative amount of services provided to those with and without access to certain modes. To begin assume that everyone can access all modes. In such a case only the relative amount of services provided by income group is relevant. The Gini coefficient, see Equation 9, and Lorenz curves provide an excellent and well used means to evaluate the relative transportation service, especially in terms of access to jobs, provided to different income groups.

At this point it is noted that generally, when the focus is to evaluate the level of equal service between groups, the groups would be organized in increasing order by the amount of the good/service provided. This would result in only positive or zero values of the Gini coefficient, with zero being considered equitable or just. However in this case, to allow for comparison between groups and consistency in analysis for each metropolitan area, the groups were organized in increasing order by income. For this reason, the Gini coefficient can have positive, negative, and zero value.

In this case many of the metropolitan areas have negative Gini coefficients. This indicates that low and/or middle income groups have higher levels of accessibility via the given mode than the high income group. If the Gini coefficient was zero it would indicate that the groups have the same accessibility levels. Finally, positive values of the Gini coefficient indicate that the high and/or middle income groups have higher levels of accessibility than the low income group.

As noted previously, for both modes, the majority of metropolitan areas have negative Gini coefficients. This indicates that in general lower income individuals are geographically located in areas with higher levels of access. This is corroborated by many studies of spatial characteristics

Description	Observed Lowest Access Via Auto	Income Category with Observed Lowest Access Via Auto	Observed Lowest Access Via Transit	Income Category with Observed Lowest Access Via Transit
New York	711,779	High	40,520	Middle
Los Angeles	760,551	High	10,994	High
Chicago	392,353	Low	11,134	Low
Dallas	437,544	High	3,009	Low
Philadelphia	283,037	High	8,192	High
Houston	338,829	High	3,584	Low
Washington DC	270,748	Low	7,574	Low
Miami	386,699	High	5,121	High
Atlanta	258,631	Middle	1,841	Middle
Boston	226,736	Low	8,757	Low
San Francisco	292,410	Low	16,578	Middle
Detroit	296,636	High	1,713	High
Riverside	209,151	Low	1,443	High
Phoenix	358,230	High	2,932	High
Seattle	204,625	Low	5,943	Low
Minneapolis	277,720	High	3,799	High
San Diego	257,841	Middle	3,867	High
St. Louis	220,345	High	2,366	High
Tampa	236,745	Low	2,349	High
Baltimore	245,149	High	4,667	High
Denver	314,731	High	5,623	High
Pittsburgh	135,398	Middle	3,898	High
Portland	239,964	Low	6,381	High
Sacramento	183,465	High	2,461	High
San Antonio	228,188	High	2,834	High
Orlando	275,395	High	1,774	Middle
Cincinnati	200,334	Middle	1,636	High
Cleveland	203,384	High	2,429	High
Las Vegas	328,906	High	2,344	High
San Jose	251,131	Low	4,357	Low
Columbus	220,178	Middle	2,725	High
Charlotte	197,264	Middle	1,780	Middle
Indianapolis	215,977	High	1,887	High
Austin	201,880	Low	3,426	High
Virginia Beach	138,608	High	1,422	High
Providence	136,533	High	2,372	High
Nashville	137,261	Middle	1,751	High
Milwaukee	202,925	High	4,371	High
Jacksonville	148,448	High	1,402	High
Louisville	161,724	Middle	2,026	High
Richmond	139,070	Middle	1,951	High
Oklahoma City	157,877	High	1,559	High
Hartford	157,086	High	1,649	High
New Orleans	111,327	High	3,120	High
Buffalo	141,115	High	2,420	High
Raleigh	186,227	Middle	1,420	High
Birmingham	101,850	Middle	756	High
Salt Lake City	229,745	Low	4,526	High

FIGURE 4 : Maxi-Min Theory of Justice applied to Access to All Jobs within 30 Minutes

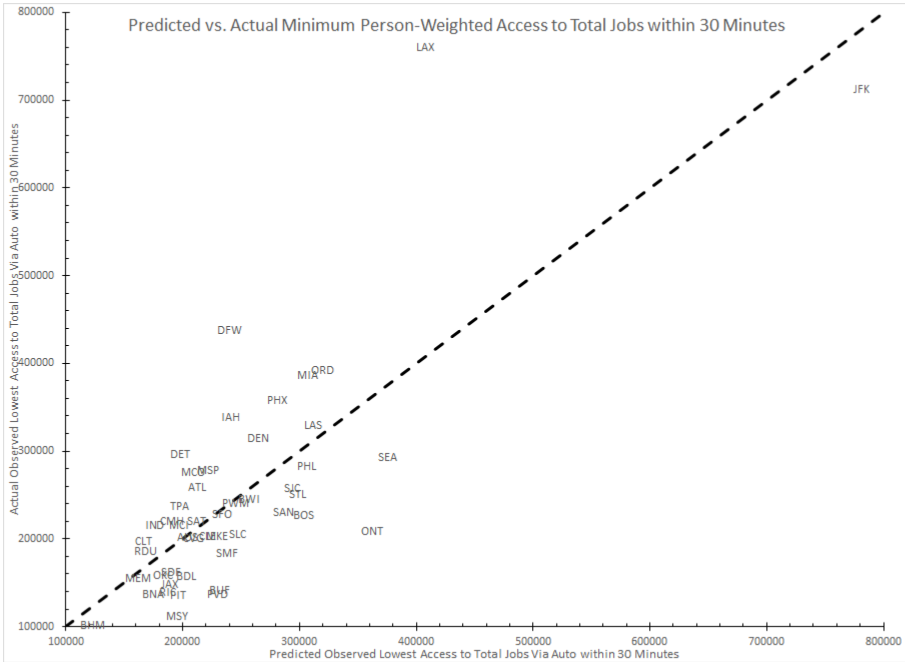

FIGURE 5 : Predicted vs. Actual Maxi-Min Theory of Justice applied to Access to All Jobs via Auto within 30 Minutes

of urban areas in the United States.

Unfortunately looking at only the resulting Gini coefficient does not provide much more information than that. However if the Lorenz curve is constructed for the region and compared to the Lorenz curve of a situation with perfectly equal levels of access, it would be further possible to determine which specific groups have higher levels of access and which have lower levels of access, within a given mode.

Furthermore, the initial assumption that all individuals have access to all modes is flawed. There are costs associated with automobile ownership or rental, as well as costs associated with using transit. For some individuals these costs are a hardship, and for others they are simply not affordable, leaving some individuals without or with limited access to these transportation modes.

Figure 6 shows the additional level of access experienced by the typical user when they can afford to take transit rather than walk, or use an automobile rather than take transit in each of the metropolitan areas. Notice that the scale for the value added by transit is significantly lower than that for automobile use. In fact the most value added in any of the metropolitan areas by transit is less than half of the least value added in any of the metropolitan areas by automobile. For this reason it may be worthwhile to consider subsidizing automobile ownership in areas without the density to support transit for other reasons, which might include environmental stewardship and reduction of congestion.

An alternative is to use ratios of two types of access. That is the case for the measures shown in Figure 7, which are calculated using Equation 13 and Equation 12.

Incorporating the information about which individuals do and do not have an automobile

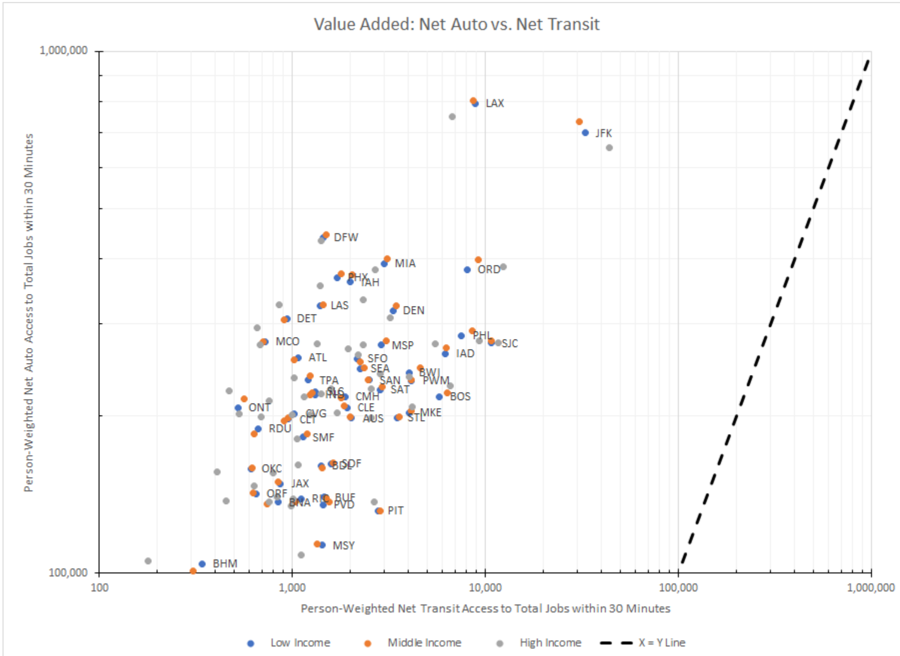

FIGURE 6 : Net Auto vs. Net Transit Access to All Jobs via Auto within 30 Minutes

makes a very large difference when using ratios. In fact for most metropolitan areas the needs ratio, which presents the ratio of transit access for the typical user who does not have an automobile to auto access for the typical user who does have an automobile, is nearly double or more than double the ratio of transit access for a typical user to the auto access for a typical user. This indicates that individuals who do not have a car, whether by choice or necessity tend to select housing near transit services and that transit services tend to be focused in areas with demand. However, the need ratio is still quite small. This reiterates the conclusion that it is worthwhile to consider subsidizing automobile ownership in areas without the density to support transit for other reasons.

CONCLUSION

In conclusion, it is apparent that each of the measures of distributive justice in transportation explored here provide valuable information regarding the justice of a regional transportation system. It is also apparent that these measures have differing strengths and weaknesses.

The absolute minimum allocation measure is excellent for local analysis particularly determining the location of problem areas in relation to job worker balance and generally gauging the level of competition experience by system users and overall shape of the distribution of transportation services. The equality of opportunity analysis provides a basis for direct statistical comparison of transportation services between groups that can be scaled to a variety of geographic areas. The Maxi-Min Theory works well for comparing between regions, once region size is controlled for, but does poorly at comparison between groups. Relative need measures on the other hand provide many opportunities to compare between groups both within a single mode and between modes, and can also be scaled within or between regions, though only between region analysis is shown

	Ratio of Transit Access to Auto Access			Needs
Description	Low Income	Middle Income	High Income	Ratio
New York	0.0659	0.0573	0.0968	0.2144
Los Angeles	0.0183	0.0175	0.0157	0.0319
Chicago	0.0302	0.0320	0.0497	0.1004
Dallas	0.0071	0.0072	0.0075	0.0127
Philadelphia	0.0360	0.0390	0.0309	0.1126
Houston	0.0099	0.0098	0.0124	0.0204
Washington DC	0.0154	0.0151	0.0213	0.1086
Miami	0.0147	0.0147	0.0144	0.0251
Atlanta	0.0078	0.0076	0.0096	0.0220
Boston	0.0432	0.0457	0.0480	0.1251
San Francisco	0.0609	0.0598	0.0647	0.1797
Detroit	0.0065	0.0064	0.0056	0.0125
Riverside	0.0076	0.0077	0.0066	0.0103
Phoenix	0.0093	0.0095	0.0082	0.0204
Seattle	0.0328	0.0342	0.0375	0.0964
Minneapolis	0.0068	0.0070	0.0059	0.0432
San Diego	0.0153	0.0159	0.0139	0.0314
St. Louis	0.0058	0.0058	0.0050	0.0266
Tampa	0.0111	0.0110	0.0101	0.0203
Baltimore	0.0242	0.0261	0.0187	0.0713
Denver	0.0185	0.0188	0.0190	0.0453
Pittsburgh	0.0317	0.0325	0.0290	0.0744
Portland	0.0103	0.0107	0.0090	0.0646
Sacramento	0.0158	0.0164	0.0150	0.0356
San Antonio	0.0172	0.0172	0.0126	0.0349
Orlando	0.0067	0.0066	0.0070	0.0124
Cincinnati	0.0111	0.0106	0.0084	0.0285
Cleveland	0.0160	0.0155	0.0122	0.0360
Las Vegas	0.0109	0.0111	0.0073	0.0221
San Jose	0.0157	0.0161	0.0157	0.0251
Columbus	0.0166	0.0160	0.0136	0.0329
Charlotte	0.0106	0.0103	0.0119	0.0204
Indianapolis	0.0123	0.0120	0.0092	0.0281
Austin	0.0191	0.0186	0.0169	0.0400
Virginia Beach	0.0125	0.0122	0.0103	0.0221
Providence	0.0112	0.0123	0.0081	0.0442
Nashville	0.0143	0.0130	0.0129	0.0422
Milwaukee	0.0296	0.0301	0.0220	0.0525
Jacksonville	0.0120	0.0114	0.0097	0.0266
Louisville	0.0183	0.0167	0.0127	0.0445
Richmond	0.0181	0.0170	0.0144	0.0425
Oklahoma City	0.0125	0.0125	0.0100	0.0214
Hartford	0.0205	0.0232	0.0120	0.0456
New Orleans	0.0301	0.0286	0.0278	0.0634
Buffalo	0.0222	0.0229	0.0171	0.0437
Raleigh	0.0090	0.0087	0.0071	0.0216
Birmingham	0.0098	0.0095	0.0072	0.0233
Salt Lake City	0.0223	0.0226	0.0202	0.0468

FIGURE 7 : Evaluating Distributive Justice Based on Ratios of Access by Mode

here.

Bibliography

[1] Benenson, I., Martens, K., and Rosenthal, A. (2010). Urban. access: high-resolution estimation of urban accessibility. In *GIScience*.

[2] Delbosc, A. and Currie, G. (2011). Using lorenz curves to assess public transport equity. *Journal of Transport Geography*, 19(6):1252–1259.

[3] Deutsch, M. (1975). Equity, equality, and need: What determines which value will be used as the basis of distributive justice? *Journal of Social issues*, 31(3):137–149.

[4] Frank, L. D. (2000). Land use and transportation interaction implications on public health and quality of life. *Journal of Planning Education and Research*, 20(1):6–22.

[5] Greenberg, J. (1981). The justice of distributing scarce and abundant resources. In *The justice motive in social behavior*, pages 289–316. Springer.

[6] Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of planners*, 25(2):73–76.

[7] Le Grand, J. (1984). Equity as an economic objective. *Journal of Applied Philosophy*, 1(1):39–51.

[8] Owen, A. and Levinson, D. (2014). Access across america: Transit 2014. *Center for Transportation Studies, University of Minnesota*, CTS14–11.

[9] Preston, J. and Rajé, F. (2007). Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography*, 15(3):151–160.

[10] Rawls, J. (2009). *A theory of justice*. Harvard university press.

[11] Verbich, D. and El-Geneidy, A. (2016). Affordable and fair? analyzing transit fare purchases, service quality, and affordability and their implications for social equity.

[12] Westen, P. (1985). The concept of equal opportunity. *Ethics*, 95(4):837–850.

[13] Zahavi, Y. (1974). Traveltime budgets and mobility in urban areas. Technical report.